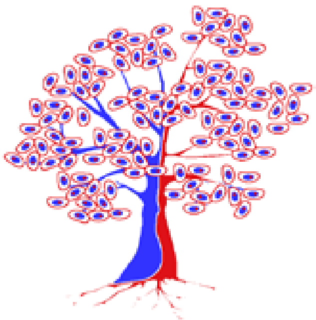
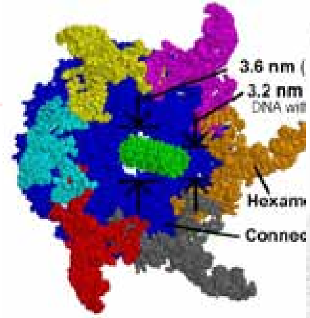
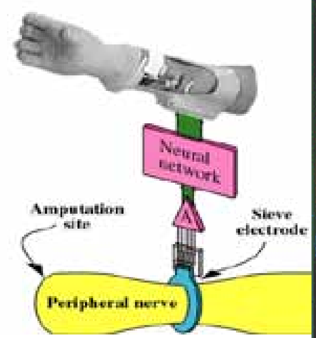
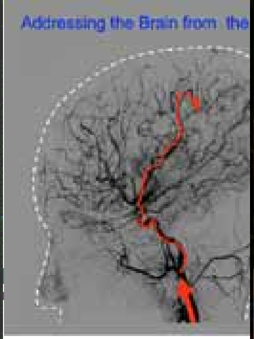
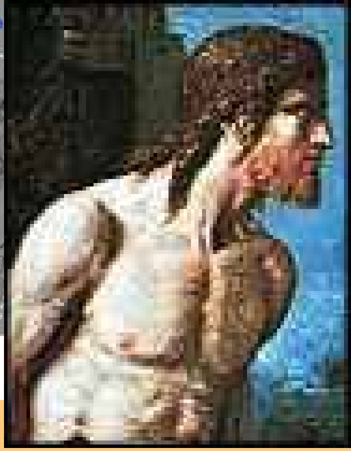










Opportunities for global governance of emerging and converging technologies

Mihail Roco

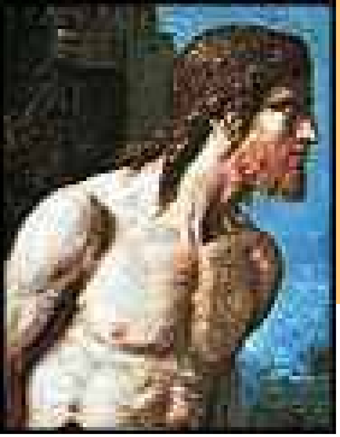
National Science Foundation and
National Nanotechnology Initiative

Converging Technologies Meeting

Sao Paolo, November 24, 2011

Topics

- ü Defining converging new technologies and core transforming tools (NBIC)
- ü Illustrations of research and education programs
- ü Global governance (policies, innovation, management) for societal benefit
- ü International study on transforming tools (NBIC2)



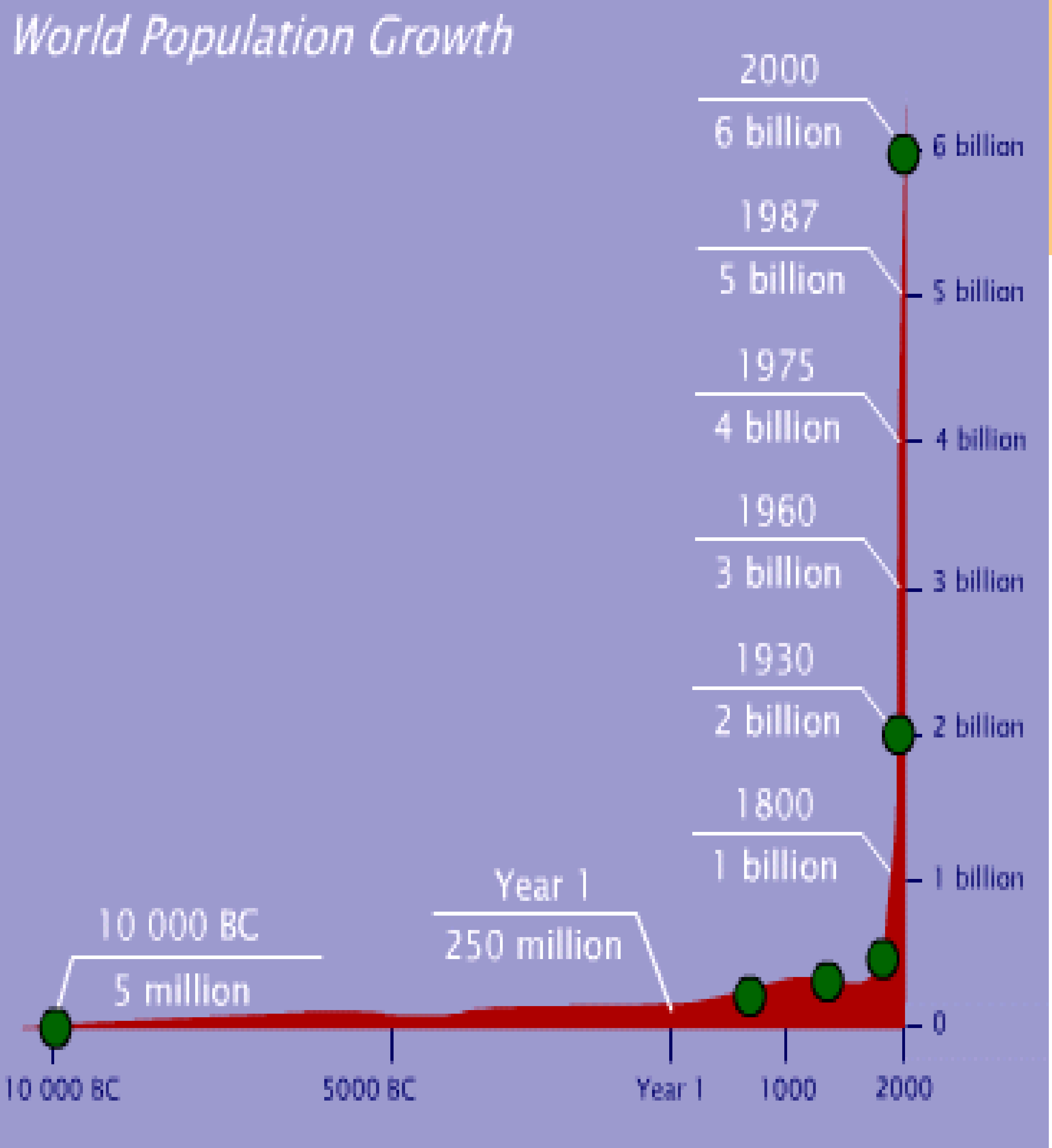
Context:
Emergence of new technologies

- Knowledge generation quasi-exponential growth
- Societal needs of radically new technologies
- Emerging technologies governance is essential

  Human potential and technological development are coevolving with benefits and risks:

  Prometheus giving the fire: "An eternity of torture"
- Technology implications are global issues:

  human development, E-W & N-S balance, safety..



More people

9-10 billion by 2050

No natural resource is sustainable with current technology: water, food, energy, key materials, climate, biodiversity

NEED OF RADICALLY NEW TECHNOLOGIES

Defining Convergence

Convergence is the process / approach to achieve reciprocal compatibility and synergism of different disciplines and technologies, by integrated application of knowledge at all length (e.g. starting from atom, gene, and neuron scale), time and complexity levels

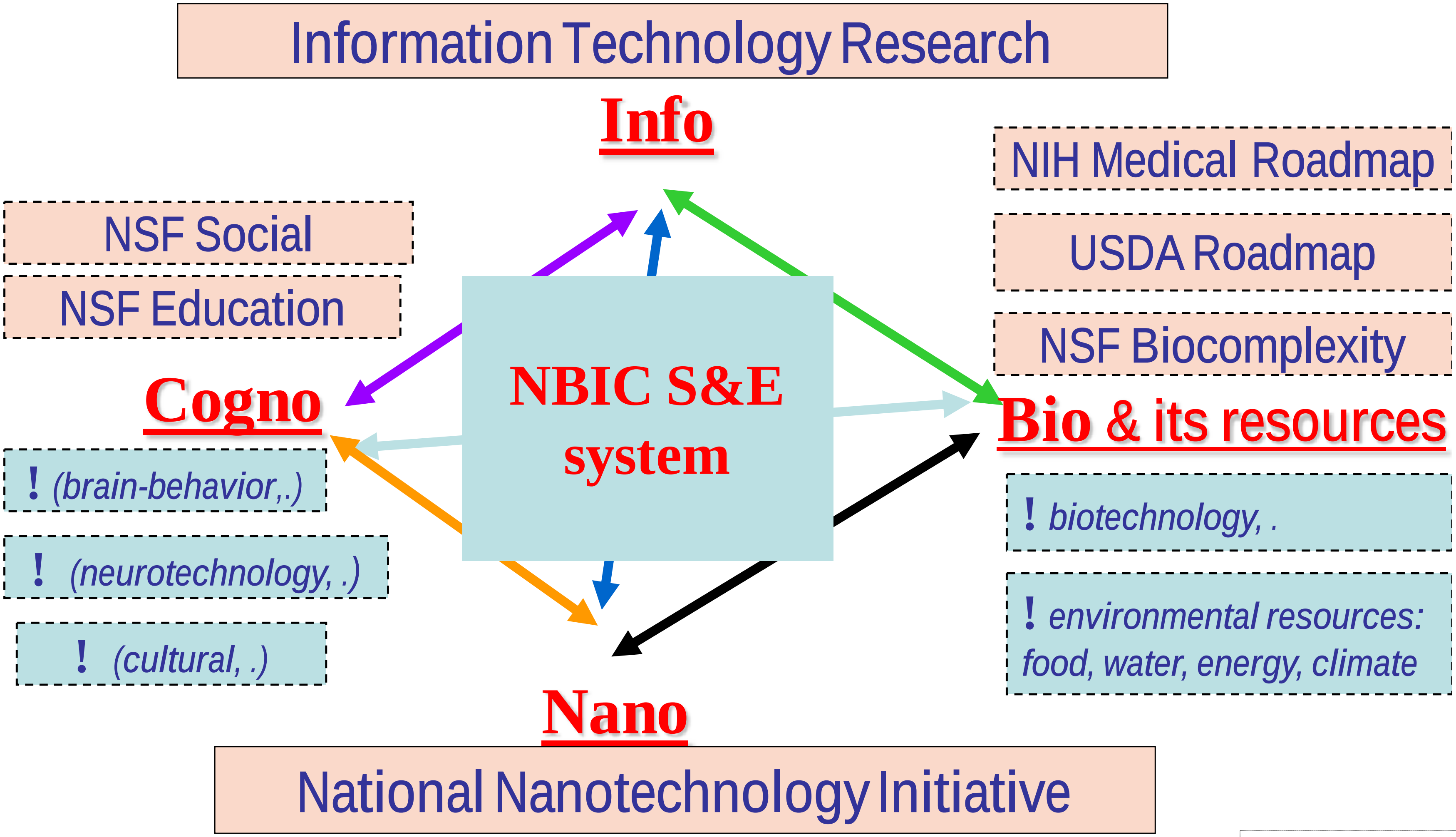
Converging Technologies Idea

Advancing an integrative approach for emerging S&E based on nanoscale material unity, system reality, and information univers (3 integrators):

- using a holistic S&E approach
- leading to new knowledge areas, NBIC platforms for S&T, and products, with shared theories and approaches
- with re-focus on people capabilities and outcomes: in working, learning, aging, physical and cognitive, collective effects
- and co-evolution of new technologies and human potential

Converging New Technologies transforming tools

(US overview in 2000-2010 ; convergence has been better developed for *small-scale* than for *large-scale systems*)



NBIC

- Nanotechnology
- Biotechnology
- Information Technology
- Cognitive Science – leading to new technologies based on computer science, psychology, neuroscience, philosophy, anthropology, economics, sociology, etc.

The meaning of NBIC convergence

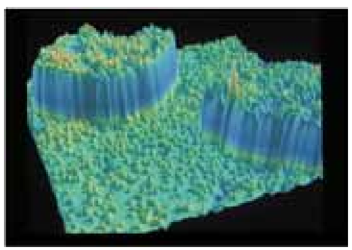
- Based on the unity of nature at the nanoscale
- Arising when the unification of science has become possible
- Arising when accelerated improvement of human potential become possible

Technology integration scales:

from material nanoscale, at human dimension, toward global scale

Cause-and-effect

Material nanoscale



~10-100 nm

Human dimension

~1 m

Global-scale perspective

~10,000 km

Known Limit Size

10^{-7}

10^{-27}

10^{7}

10^{27}

Known Limit Size

M.C. Roco, Nov 24 2011

Technology Integration at Human Dimension

The "Push" *The "Pull"*

Human – communication / societal / virtual integration

Euristic, software-based

Human-technology system

Cognitive needs

Bio-physical needs

Physic, hardware-based

Human- machine / environment / sensor integration

Technology Integration toward Global Scale

The "Push" | *The "Pull"*

Global communication / interaction / economy / values ..

Euristic, softare-based

Global technology system

Cognitive needs

Bio-physical needs

Physic, hardware-based

Geoengineering / astronomy / space exploration / climate..

Convergence: timely, broad opportunity

2000 →

- Material unity at the nanoscale and technology integration from the nanoscale, "science beyond the Renaissance ideal"
- Powerful transforming tools (nano-bio-info-cogno-system) and technology platforms developing concurrently at the confluence of disciplines, integrated from the nanoscale
- Towards an "universal domain of exchange" for ideas, etc.
- Improvement of human potential becomes possible
- New social relations (adapting organizations and business)
- New opportunities for innovation; for anticipatory, holistic and adaptive governance measures ('Learning before doing')

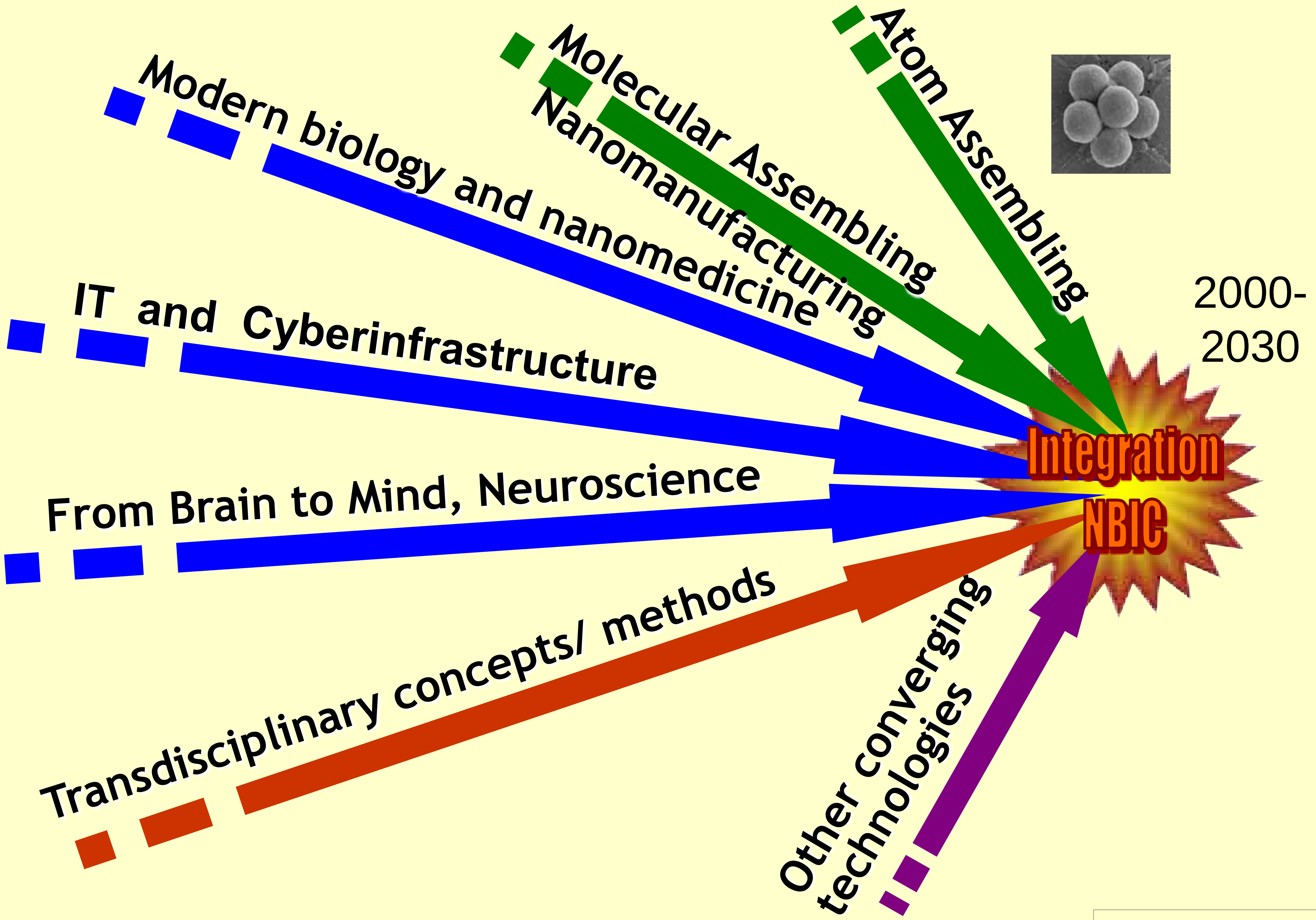
Essential improvements in each technology tool domain

- the paradigm changes in the next decade

require a fresh look at research and education

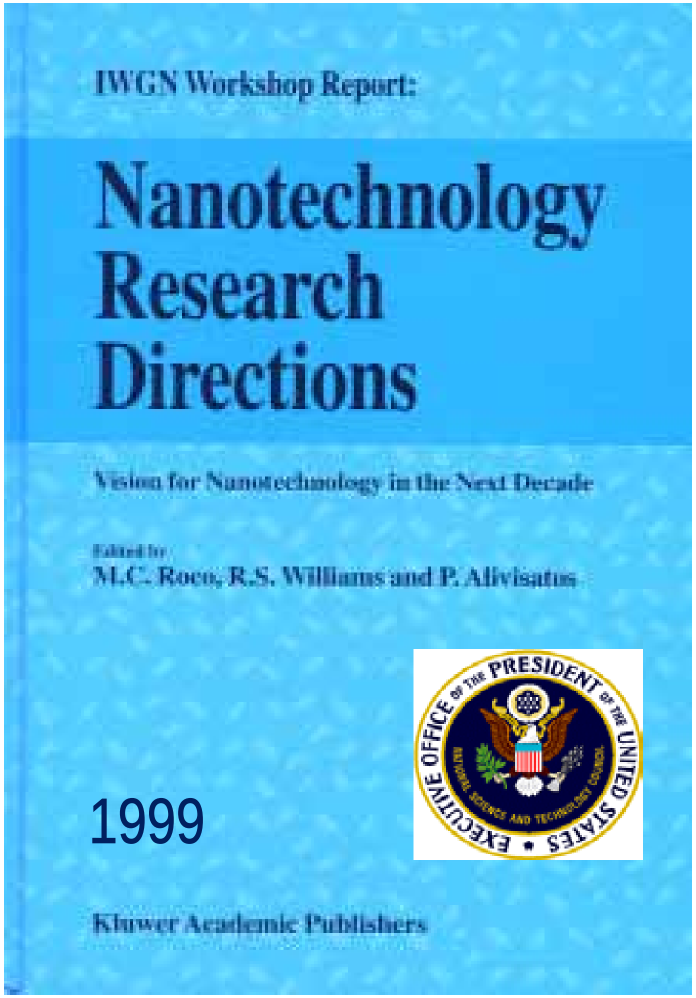
- Nano T: from scientific discovery to technological and medical innovation
- Bio T: advancing towards molecular medicine and pharmaceutical genome
- Info T: the quest for smallness and speed will be enhanced by new architectures, 3-D integration, functionality and integration with applications
- Cognitive T: explanation of human behavior from physico-chemical-biological processes at the nanoscale, neuroscience, and system approach
- System-based T: large, hierarchical, complex systems

NBIC: *concurrence of capabilities*

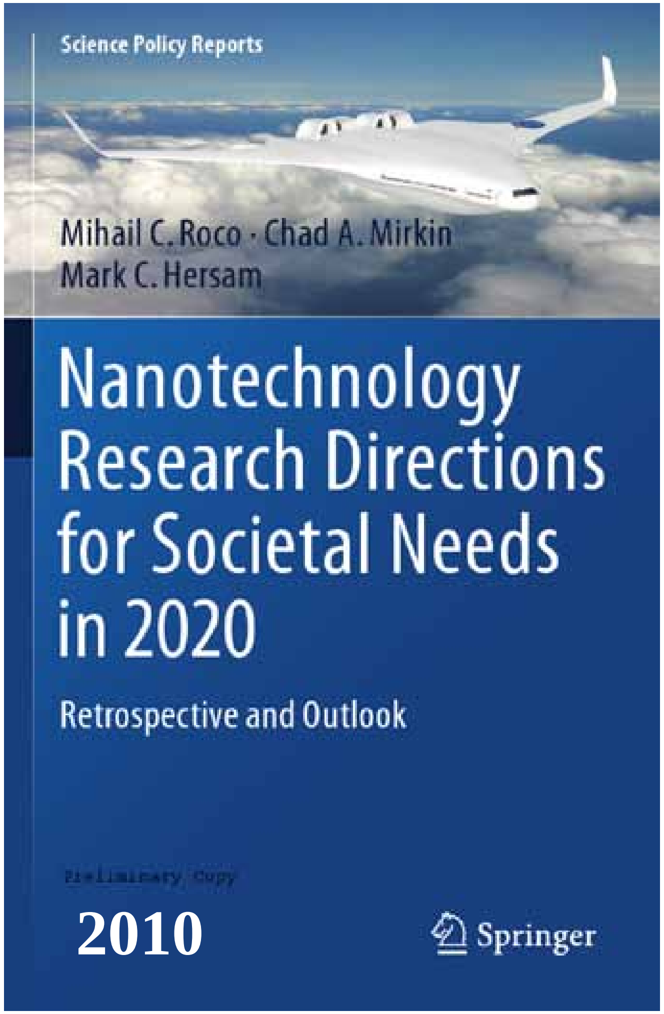


Example for one NBIC component: Long-term nanotechnology research directions (2000-2020)

Nano1 (2000-2010)



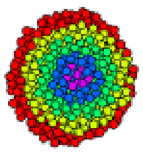
nano2 (2010-2020)



NSF/WTEC, www.wtec.org/nano2/

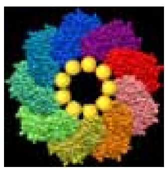
Nano Perspective: Five Generations of Products and Productive Processes after the level the complexity, dynamic behavior and transdisciplinarity

Timeline for beginning of industrial prototyping and NT commercialization



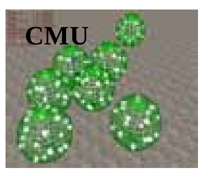
1st: Passive nanostructures (1st generation products)
Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

~ 2000



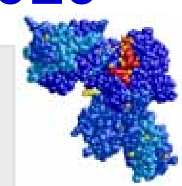
2nd: Active nanostructures Ex: 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures

~ 2005



3rd: Systems of nanosystems
Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary

~ 2010



4th: Molecular nanosystems
Ex: molecular devices 'by design', atomic design, emerging functions

~ 2015-2020

5th: Converging technologies
Ex: nano-bio-info from nanoscale, cognitive technologies; large complex systems from nanoscale

New R&D challenges

	R&D →		*Broad Use*
IT	1960	-	2000
BIO	1980	-	2010
NANO	2000	-	2020
NBIC	2010	-	2030

Reference: AIChE Journal, Vol. 50 (5), 2004

Examples of 3rd and 4th generation of nanotechnology products – toward convergence

- Artificial organs using nanoscale control of growth
- Subcellullar intervention for treatment of cancer
- Bioassembly (ex. use of viruses) of engineered nanomaterials and systems
- Evolutionary systems for biochemical processing
- Sensor systems with reactive mechanisms
- Nanoscale robotics on surfaces and 3-D domains
- Simulation based experiments and design of engineered nanosystems from basic principles
- New molecules designed as devices
- Hierarchical selfassembling for micro or macro products

Focus on converging technologies: 2010-2030

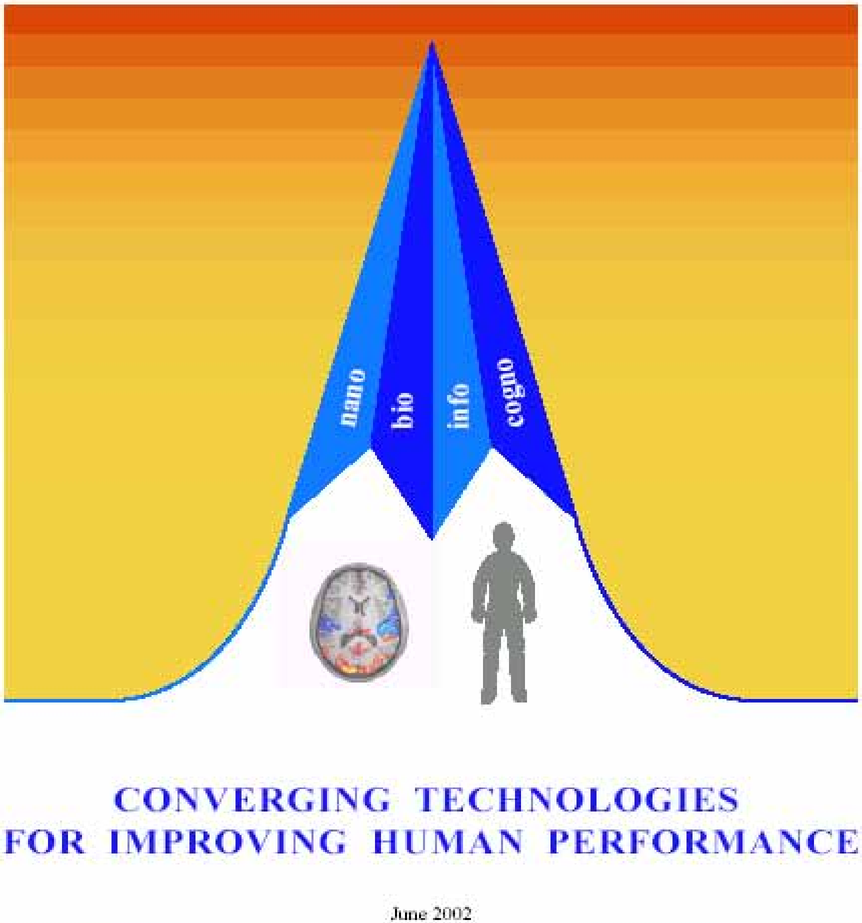
Nanotechnology **convergence** with bio, info and cogno, and **bifurcation** of nanosystem architectures

- Guided assembling
- Evolutionary
- Engineered molecular design and guided hierarchical selfassembling
- Robotics based
- Reconfigurable sensorial systems
- Biomimetics . . . .

  - ? New carrier of information instead of electron charge
  - ? Manufacturing by nanomachines
  - ? Extending human potential
  - ? Collective cognitive capabilities . . . .

Five volumes on convergence

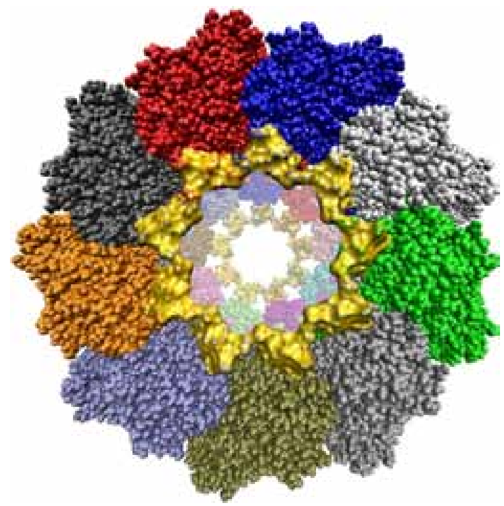
2003, 2006 and 2007 Springer; 2004 NYAS;
NSF 2004 (Organizations and Business)



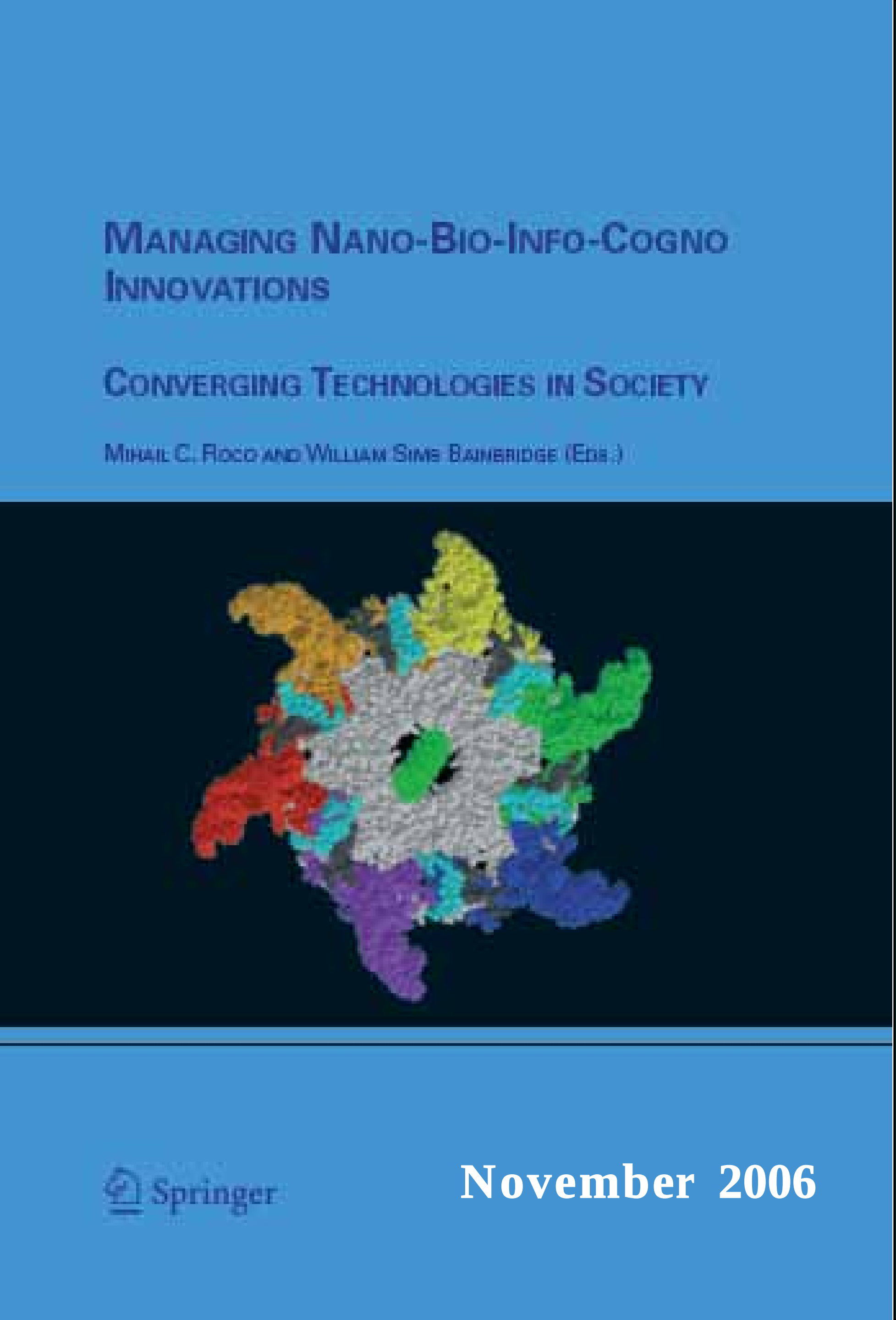
Workshop, Dec. 2001
wtec.org/converging technologies/
(in Springer, 2003)

Coevolution of Human Potential and Converging New Technologies

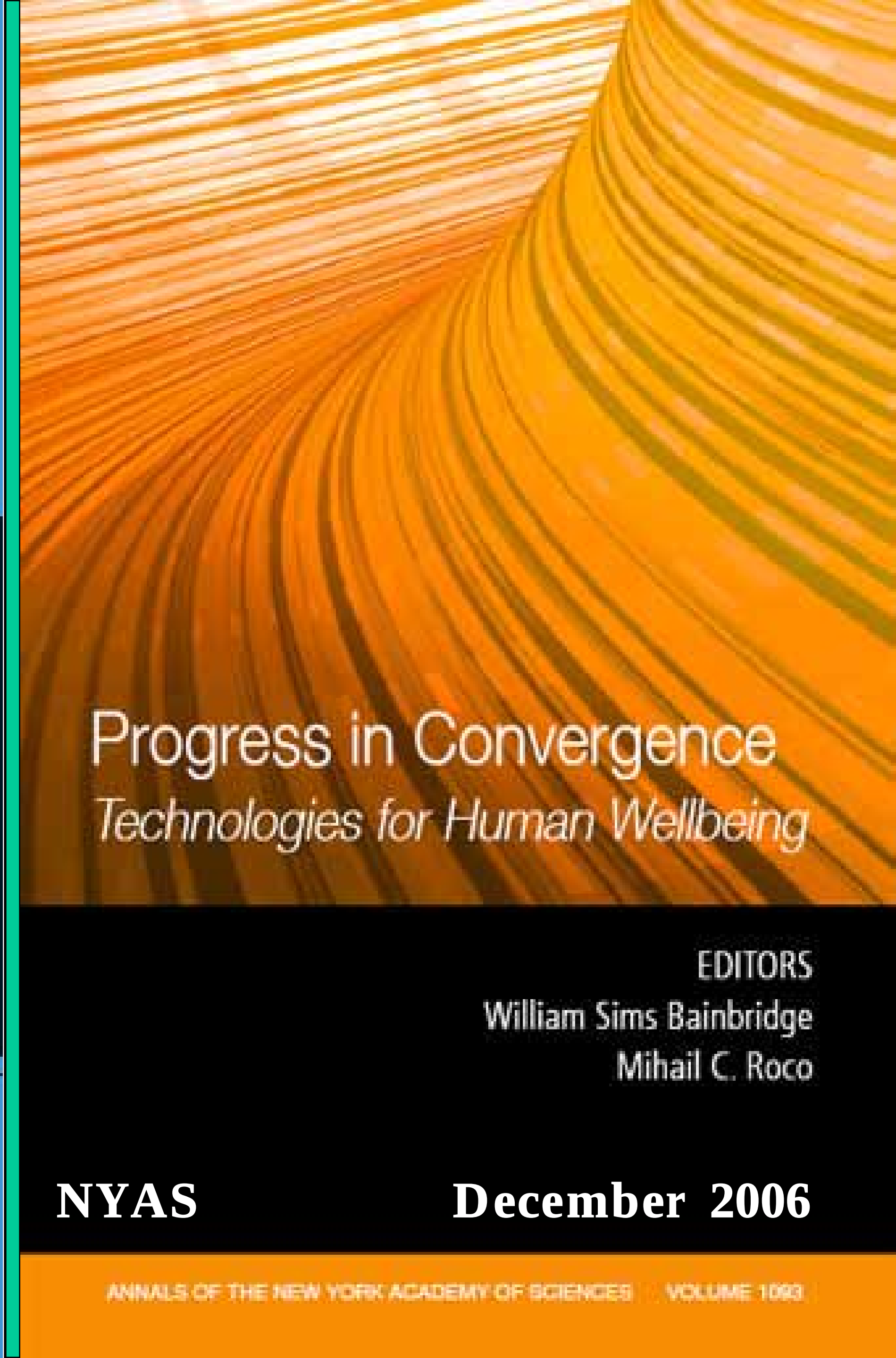
(Feb. 2003 and Feb. 2004 meetings)



In: Annals of the New York, Academy of Sciences, Vol. 1013, 2004
(M.C. Roco and C. Montemagno)

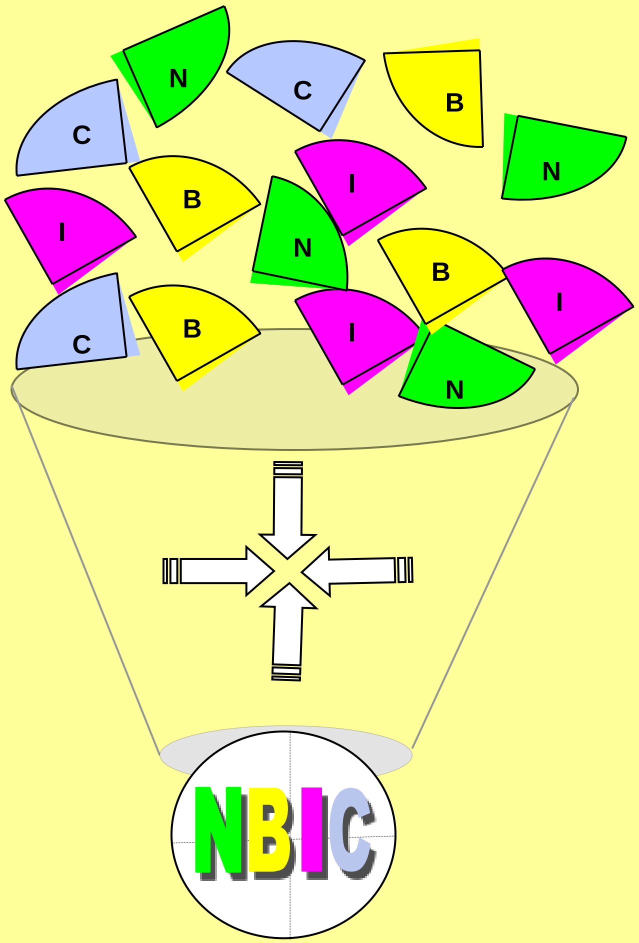


November 2006



NYAS **December 2006**

Commercializing and Managing the Converging Technologies (2004)



NSF sponsored workshop (September 2003) and report (April 2004)

Northwestern University, Center for Technology & Innovation Management (CTIM)

Topics

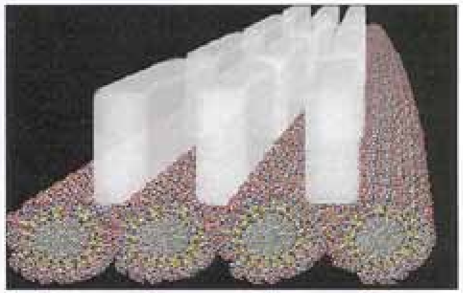
- ü Defining converging new technologies and core transforming tools (NBIC)
- ü Illustrations of research and education programs
- ü Global governance (policies, innovation, management) for societal benefit
- ü International study on transforming tools (NBIC2)

International Context

International interest after the NBIC report made public in 2002: in EU, Japan, Korea, Switzerland, France, Netherlands, Russia, China, Brazil, others

Ethical concerns: develop responsible organizations with capability to address NBIC implications; need for global surveys to avoid surprise

The largest public funding for NBIC R&D: in US (distributed); EU (program solicitations), Japan (center and program), Russia (centers), China (priority area); all inspired or influenced by the NBIC report

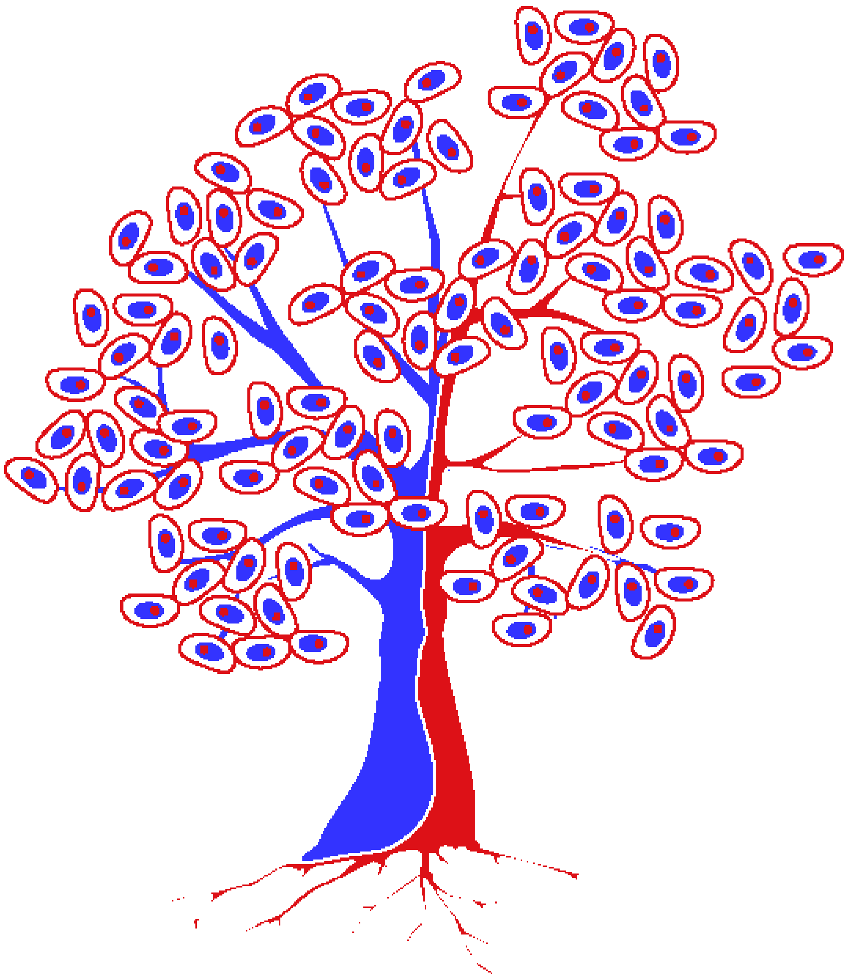


U.S.: Seed R&D programs since 2002

- Converging S&E components in: **Nanoscale Science and Engineering**, **ITR**, **Biocomplexity**, **Sensors** (all 2002-)
- DARPA **nano-bio-info-cognitive** research focus (2002 -)
- Improving human performance in **NSF Human and Social Dynamics** (2003-)
- NSF **SBIR** focus on converging technologies (2003-2004)
- NSF-NIH on computer **simulation of the brain** (2004-)
- NSF centers for "**learning to learn**" (2004 -)
- NASA **improving human performance** for space exploration, and nano-bio-info programs (2004 -)
- About ten **NSF and NASA centers** on domains of NBIC (2004 -)

Example R&D program:

Vision 2020 for Regenerative Medicine (2004-)



Combine

- precision assembly of matter (nanotechnology),
- building blocks of living systems biotechnology),
- using spatial-temporal flow of information (IT),
- and cognitive sciences.

Working group 6 Federal agencies (NIH, FDA, DOD, NASA, DOC, NSF; 1/2004)

Example program:

NSF's Science of Learning Centers
- from brain to learning processes using NBIC -

Center for Excellence for Learning in Education, Science, and Technology (CELEST), Boston U. (http://cns.bu.edu/CELEST/)

Center for Learning in Informal and Formal Environments (LIFE), U. of Washington, Stanford U., SRI International, (http://life-slc.org/)

Pittsburgh Science of Learning Center for Robust Learning (PSLC), Carnegie Mellon U. and the U. of Pittsburgh (http://www.learnlab.org/)

Spatial Intelligence and Learning Center (SILC),
Temple U., Northwestern U., the U. Chicago, U. Penn., Chicago Public Schools

The Temporal Dynamics of Learning Center (TLC)
UC San Diego (UCSD), with participation from scientists at Rutgers University, Newark, Vanderbilt University, UC Berkeley,

Visual Language and Visual Learning Center (VL2)
Gallaudet University

http://www.nsf.gov/home/crssprgm/slc/

DARPA programs for FY 2003 (examples)

- Brain Machine Interface

  Communicate with the world directly through brain integration and control of peripheral devices and systems

- Metabolic Engineering

  Develop methods for controlled metabolism in cells, tissues, organs, and organisms needed by the U.S. military

- Exoskeleton for Human Performance Augmentation

  Technologies to remove the burden of mass and increase the soldier’s strength, speed, endurance

- Continuous Assisted Performance

  Prevent the degradation of cognitive performance caused by sleep deprivation

NASA programs for FY 2003 (examples)

- Goals for future NASA systems

  autonomous, resilient, ultraefficient, evolvable, highly distributed, self-sufficient (attributes of biosystems, to be done with NT, IT and CT)

- Revolutionary products

  human sensor, plane of the future,
  improving human performance of astronauts

- NASA-NCI at convergence of nano-bio-info-health
- Four academic research centers based on integration

Seed NBIC research activities in industry
(examples since 2002)

- **IBM**
- **DuPont**
- **HP**
- **Rockwell Scientific**
- **Intel**
- **General Electric**
- **Mobil**
- **Many entering this field**

International interest: US, Japan, EC, Korea, Switzerland, France, others

Examples of new transdisciplinary domains (1) (NBIC)

- **Quantum information science** (IT; Nano and subatomic physics; System approach for dynamic/ probabilistic processes, entanglement and measurement)
- **Eco-bio-complexity** (Bio; Nano; System approach for understanding how macroscopic ecological patterns and processes are maintained based on molecular mechanisms, evolutionary mechanisms; interface between ecology and economics; epidemiological dynamics)
- **Neuromorphic engineering** (Nano, Bio, IT, neurosc.)
- **Cyber-physical systems** (IT, NT, BIO, others)
- **Synthetic biology** (Bio, Nano, IT, neuroscience)

Examples of new transdisciplinary domains (2) (CT - NBIC)

- **Nano sensors in the environment** (Nano, bio, IT networking, environment)
- **Emerging technologies for sustainable development** (energy conversion and storage using nano, filtration of water using nano, using exact nanomanufacturing for reducing environmental quality and weather implications, using nanotechnology to reduce consumption of raw materials, energy from fusion, etc.)
- **Adaptive systems engineering** (neuroscience, cognitive technologies, adaptive systems for unpredicted events, etc.)
- **Enhanced virtual reality** (using nano, IT, cognitive, BIO; personalized learning, reverse engineer the brain)

Synthetic Biology

Approach to engineering biology, to make or re-design living organisms, so that they can carry out specific functions. Involves making new DNA that does not already exist in nature, using NT and IT.

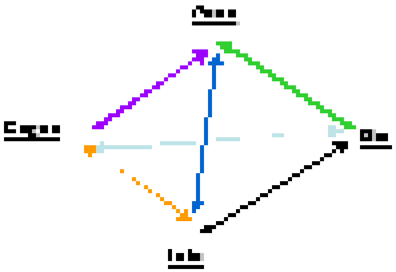
Examples:

- **Bio-energy:** Cells are being engineered to consume agricultural products and produce liquid fuels
- **Drug production.** Bacteria and yeast can be re-engineered for the low cost production of drugs (ex: Lipitor)
- **Materials.** Recombinant cells have been constructed that can build chemical precursors for the production of plastics, textiles
- **Medicine.** Cells are being programmed for therapeutic purposes. Bacteria and T-cells can be rewired to circulate in the body and identify and treat diseased cells and tissues.

Converging New Technologies

- *long-term implications* -

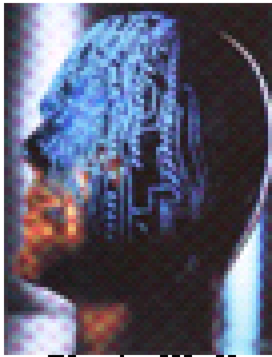
- Expanding human cognition and communication
- Improving human health and physical capabilities
- Enhancing societal (individual, group) outcomes, including new products and services
- Changing societal relationships, including shaping
  - policies for R&D investments and infrastructure,
  - models for organizations and business
  - risk governance for innovative technologies
- Personal and national security
- Unifying science and education - for CT-NBIC development
  - improving education



Examples of NBIC visionary goals

NSF Workshop, Dec. 2001

- **Improve intellectual capacity and productivity** through mental status and intelligent environment
- **Accelerate learning** using converging technology
- **Brain-to-brain and human-machine interfaces** (neuromorphic engineering)
- Portable "**Personal broker**"
- **Expanding visual communication**
- **Improve group communication and creativity**
- **Enhance human physical and sensorial capabilities**
- **Aging active with dignity**



Physics World

Exemples of revolutionary new products and services

- Bio-robotics (ex: artificial muscle)
- Systems based on emergent intelligence
- Bio-chem-lab on a chip
- Neuromorphic devices and systems
- New generation of means of transportation
- Virtual reality ecosystem
- Converting chemical energy at low temperatures

(NSF Workshop, Dec. 2001)

Potential of Converging Technologies
to address core goals of individuals and society
- medium term implications -

- NBIC strategy for technological and economical competitiveness
- Enhancing individual and group abilities, productivity and learning
- New patterns for S&T, business, economy, and society
- Changing human activities towards the "innovation age"
- Sustainable and "intelligent" environments

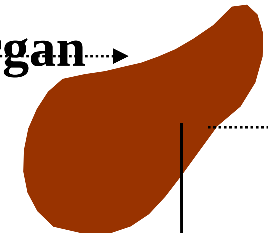
(NSF Workshop, Dec. 2001)

Examples of levels for intervention of nanobiotechnology

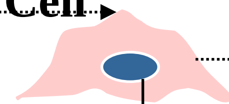
4 generations of products for human life extension

Human

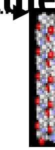
Organ



Cell



Molecule



- **(2nd)**Sensors for in vivo monitoring
- Localized drug delivery
- Neural stimulation
- Cardiac therapies
- Artificial organs

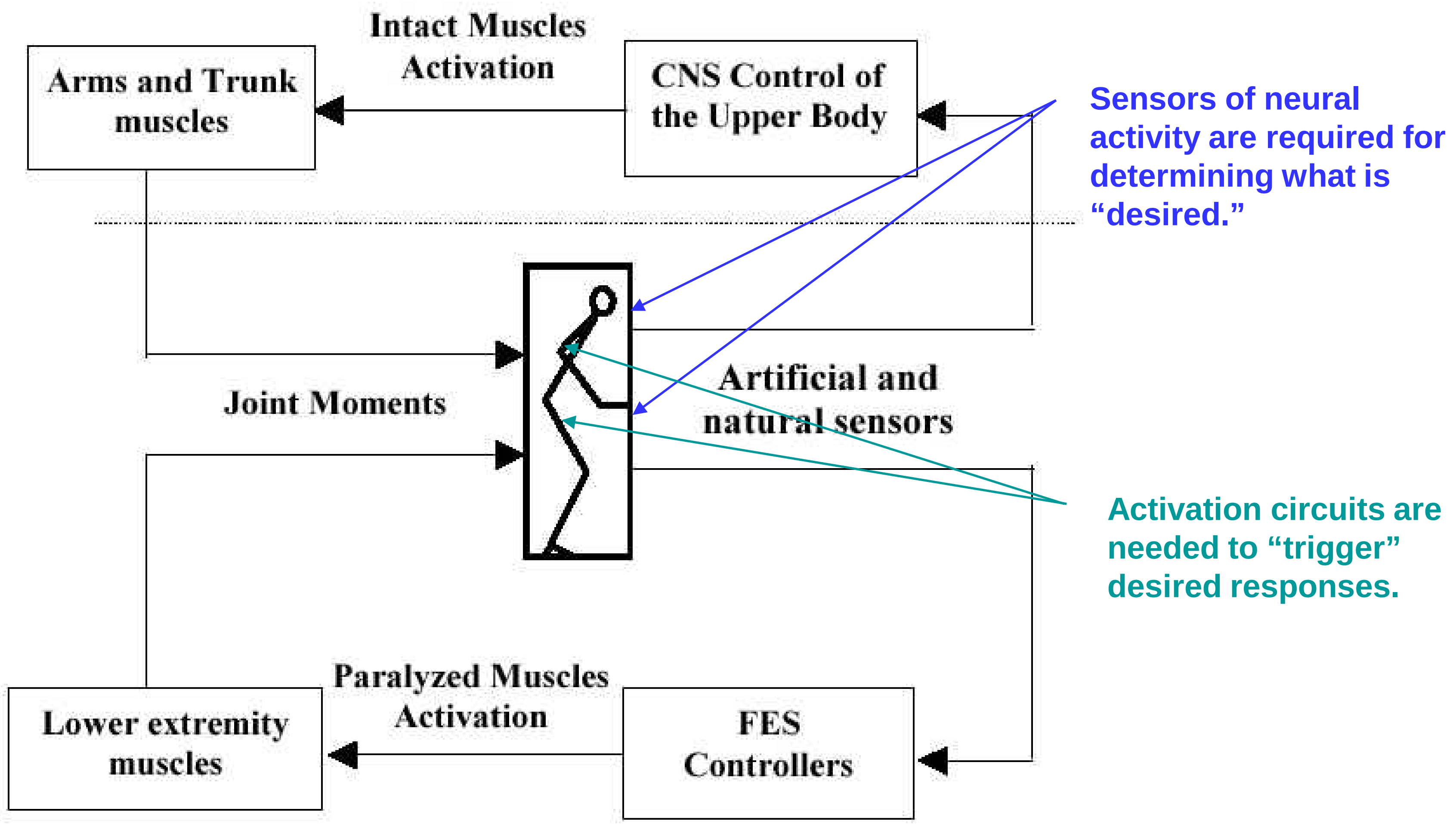
- **(1st)** Joint replacement
- Non-invasive and invasive diagnostics for rapid patient monitoring
- Cognitive-assist devices
- Targeted cancer therapies

- **(3rd)** Improved cell-material interactions
- Scaffolds for tissue eng.
- **(4th)** Genetic therapies
- Cell ageing
- Stem cell therapies

- Localized drug delivery
- Fast diagnostic techniques
- Gene therapy devices
- Self-assembly structures

(NBIC Report, 2002)

(a) Can we connect nanoelectronics to biology?
What is currently possible?

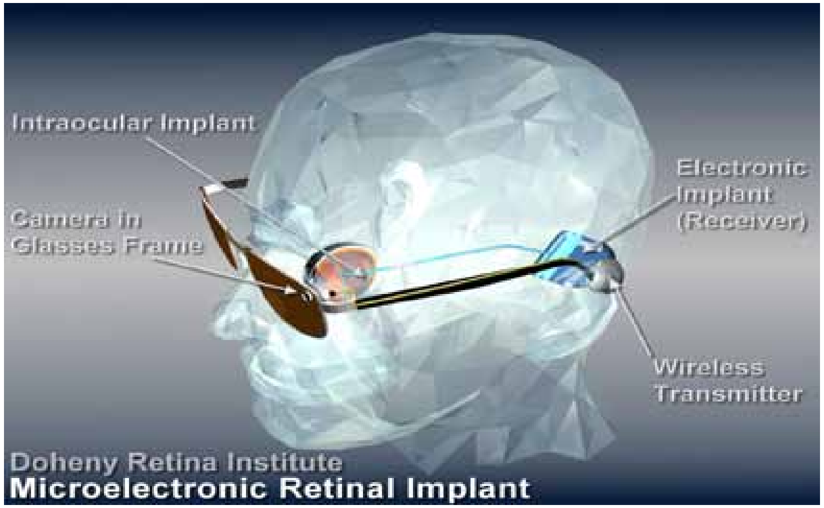


University of Arizona

(b) Interfaces with human cells and sensors

Examples:

- J. Heath (Caltech): Sensors for subcellular processes: **continuous monitoring and interaction**
- R. Greenberg: **Interfacing to the sensory human nervous** system via chemical, electrical, mechanical, magnetic signals
- **Various prosthesis**: may increase visual (infrared, X-ray, etc.), audio, smelling, tactile, nerves, or other capacities
- Doheny Retina Institute: **artificial retina**



(c) Active implants in cardiology

Nanoscale nerve-device interfaces
Nanoelectronics, biocompatible

for

- Interpreting brain message for variable effort
- Blood pressure regulation
- Bionic treatment of heart failure (Keinji Sunagawa, Japan)

(d) Brain - Machine Interface

Ex:

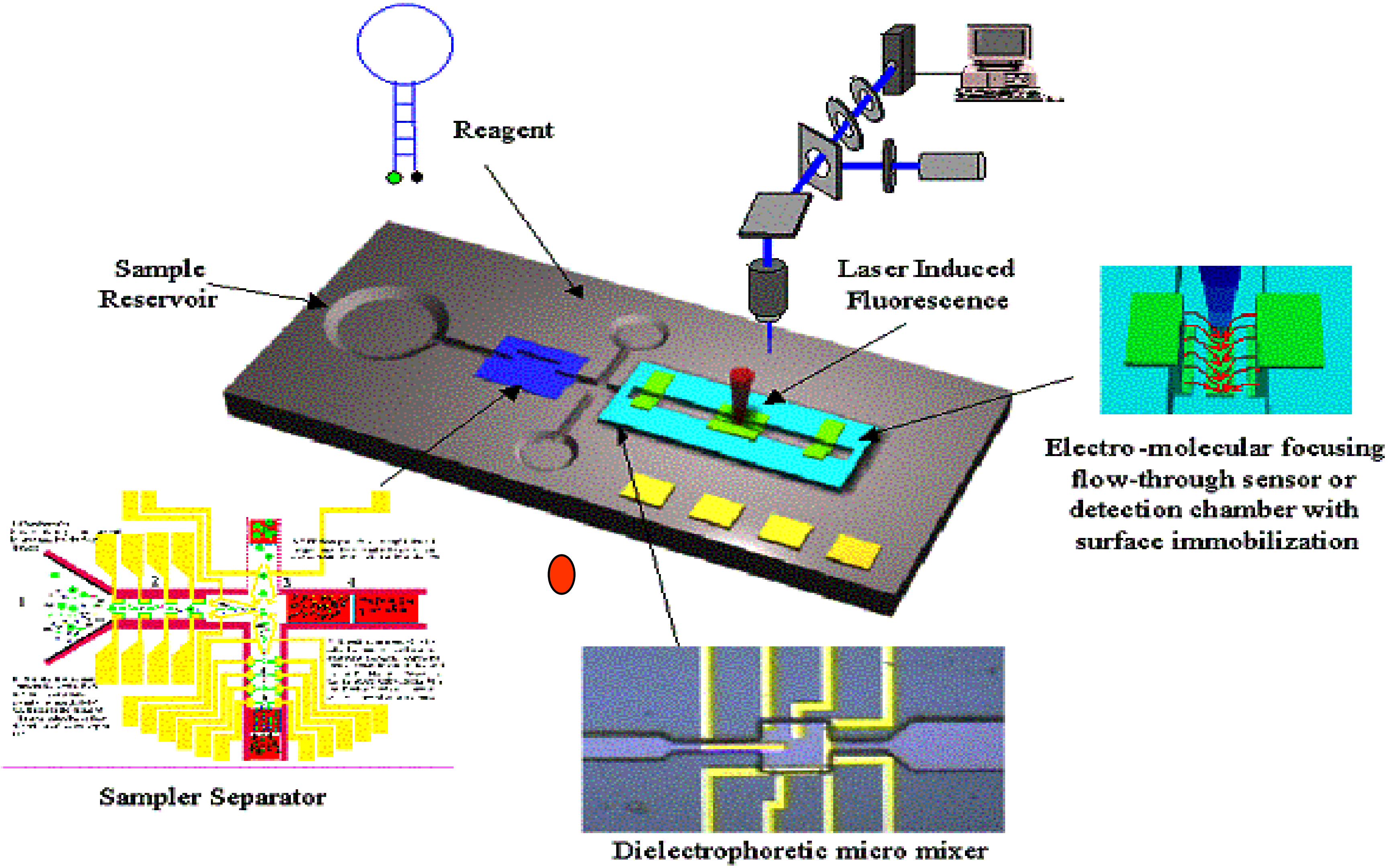
Use technology to transfer information from one human sensor to another.

The brain can learn to use a new sense. The brain regions respond to more than one sense.

- Paul Bach-y-Rita: practical device for sight using a two-dimensional sensor on the tongue
- Richard Cytonic: Synthesia (multisensing, combining multiple senses, perceptual grouping)

(e) Biochips as integrated multifunctional systems

<u>Detection of illnesses using saliva</u>: the detection chamber that includes the different ligand for simultaneous optical detection of multiple analytes **(D. Wong, C.-M. Ho, UCLA)**



Topics

- ü Defining converging new technologies and core transforming tools (NBIC)
- ü Illustrations of research and education programs
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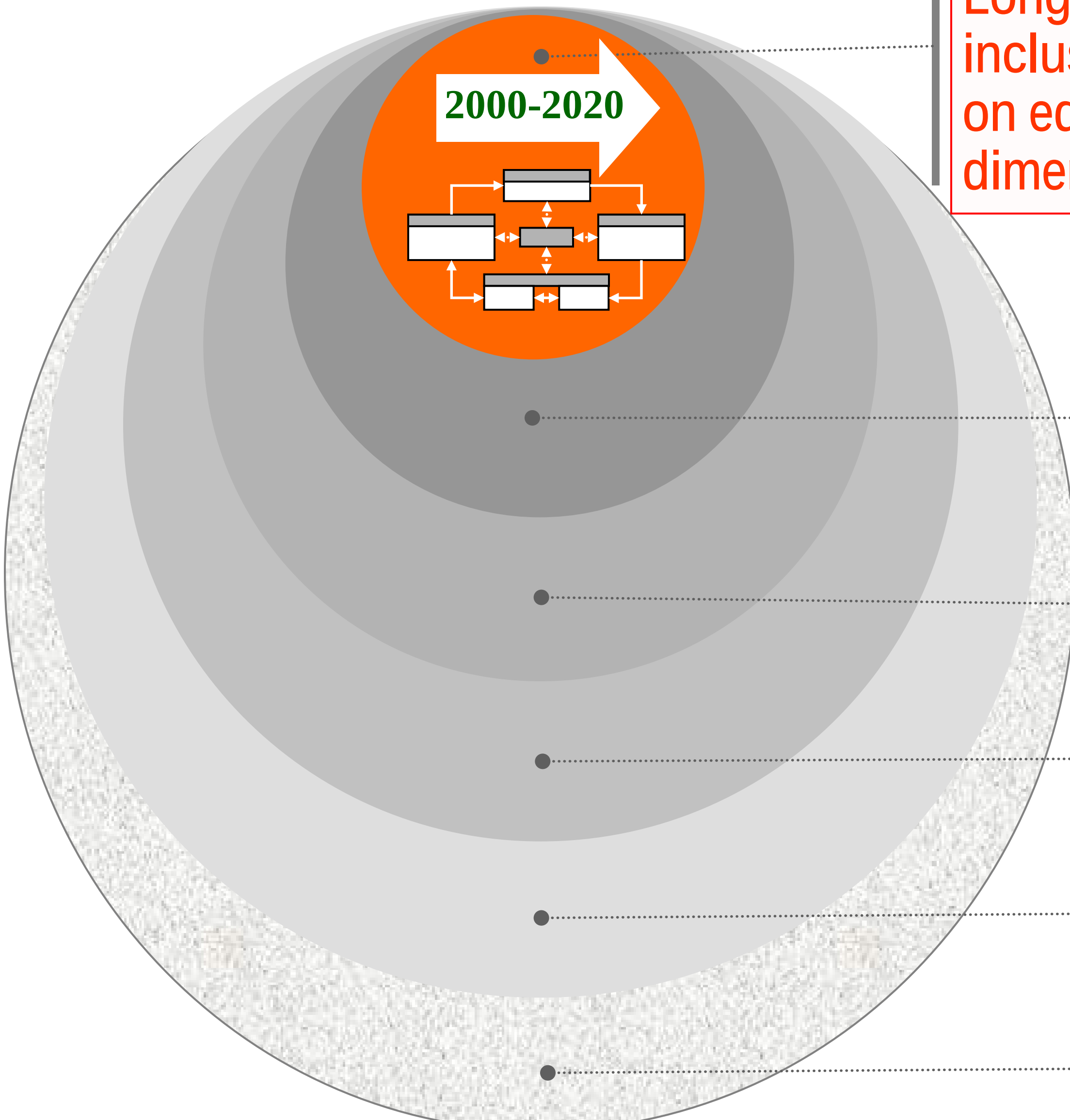
Converging Technologies GOVERNANCE OVERVIEW



Core Governance Process:
Long-term view, transforming, inclusive, horizontal/vertical, priority on education, addressing societal dimensions, risk governance

Main Actors:

R&D Organizations
(Academe, industry, gov.)

Implementation Network
(Regulators, business, NGOs, media, public)

Social Climate
(Perceived authority of science, civil involvement)

National Political Context

International Interactions

M.C. Roco, Nov 24 2011

Governance of CT development: four main functions

A. TRANSFORMATIVE

B. RESPONSIBLE DEVELOPMENT

C. INCLUSIVE and COLLABORATIVE

D. VISIONARY

Reference: “Global Governance of Converging Technologies”, MC Roco, J. Nanoparticle Res., 2008, 10 11

Possibilities for a Global Governance of CT
General approach

- *Facilitate and provide reference models to the global self - regulating ecosystem (system too complex for top-down):*

- *Focus on bottom-up and lateral interactions in each country and int.*

- *System of global communication and participation* in all phases of governance, facilitated by international organizations

Possibilities for a Global Governance of CT

A. Transformative function

- Support tool development, knowledge creation, innovation and informatics, and commercialization for CT

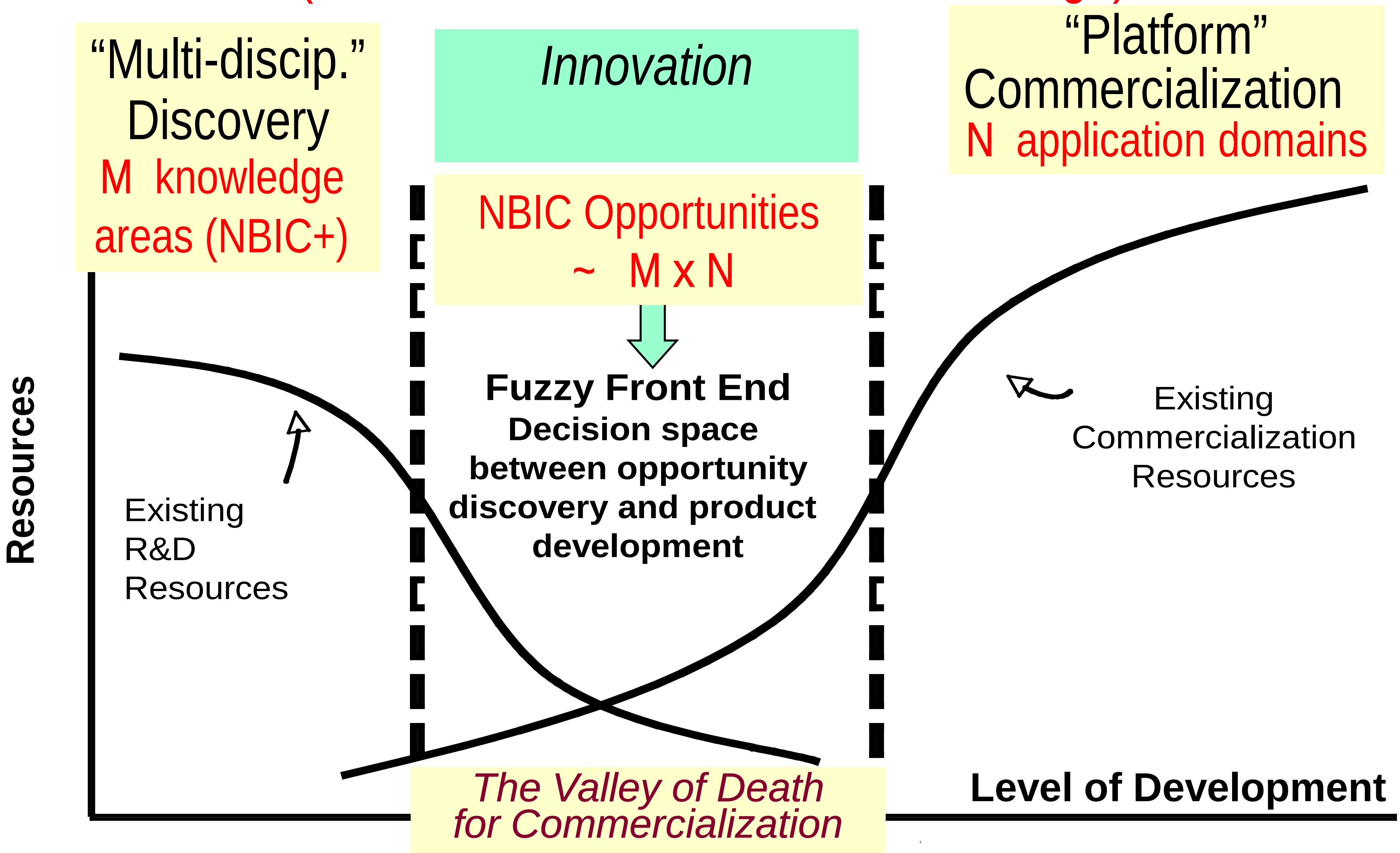
- Creating better opportunities for development of CT in developing countries

- Develop common capacity for application of CT: nomenclature, metrology, standards, patent evaluation, databases, and EHS methodologies including for a predictive approaches with international use

- Use "incentives" and "empowering stakeholders" in the open and global ecosystem

NBIC for enhanced innovation

(creation of wealth based on knowledge)



INNOVATION opportunities increase for NBIC (~ M x N times)

B. Responsible development function

- Development with priority of general benefit applications such as increasing productivity and sustainable manufacturing, and availability of common Earth resources such as water, food, energy, and sustainable clean environment

- Voluntary measures and science-based decision for risk management

- Public inclusion and participation in global activities

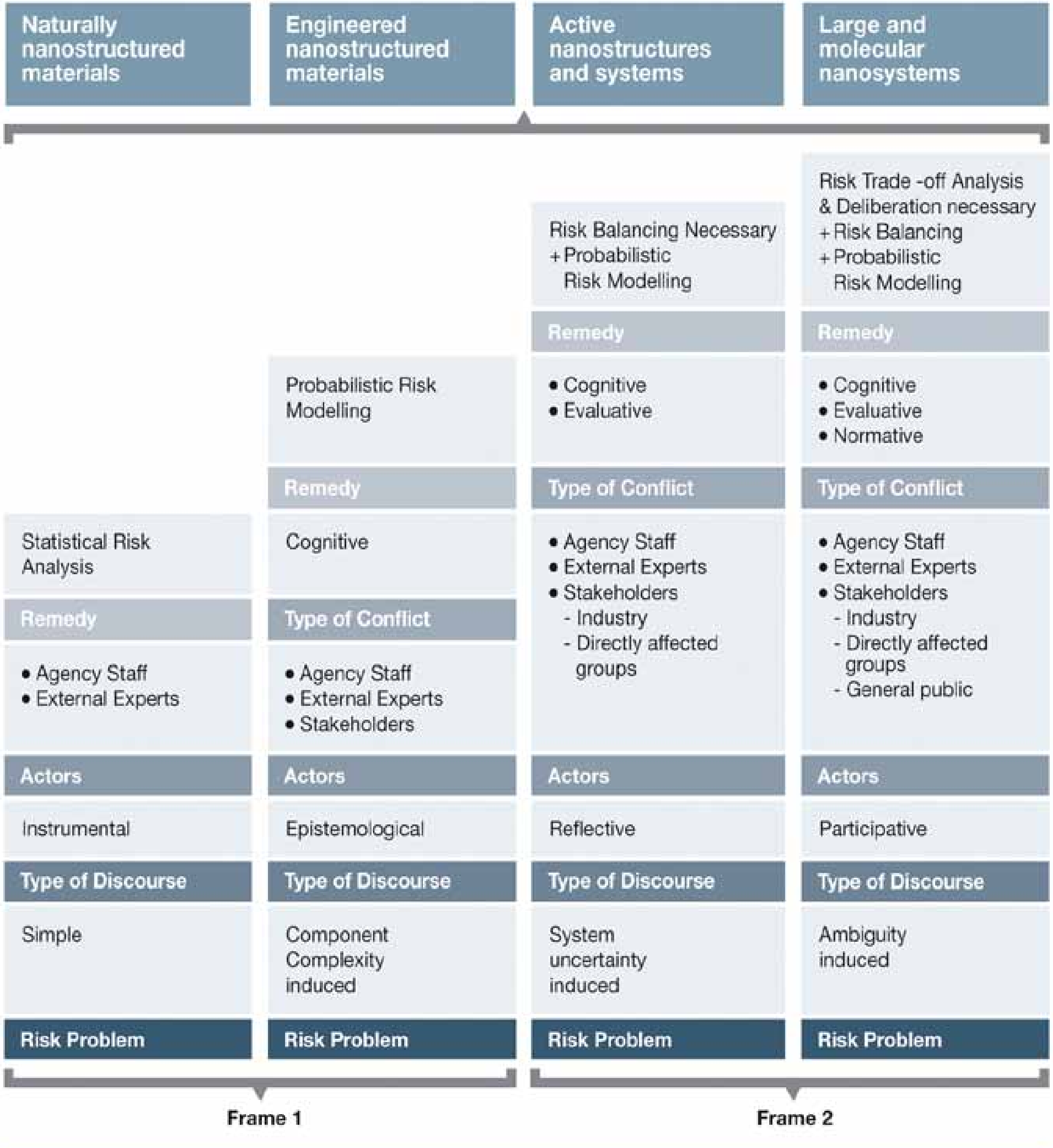
- Develop organizational capacity for effective oversight

Context:
SPECIFIC RISKS INDUCED BY EMERGING TECHNOLOGIES

- Increased technology complexity and uncertainty in comparison with traditional technologies

- Interdependency with wide ranging effects throughout our industrial and social systems, including convergence and integration trends

- Increased importance of societal implications which may not be known at the release of the technology. Importance of reducing the time delay between development of scientific knowledge and evaluation of societal implications



The Risk Management Escalator and Stakeholder Involvement

(from Simple via Complex and Uncertain to Ambiguous Phenomena) with reference to nanotechnology

Building capacity for responsible development

Multi-level structure of NBIC risk governance

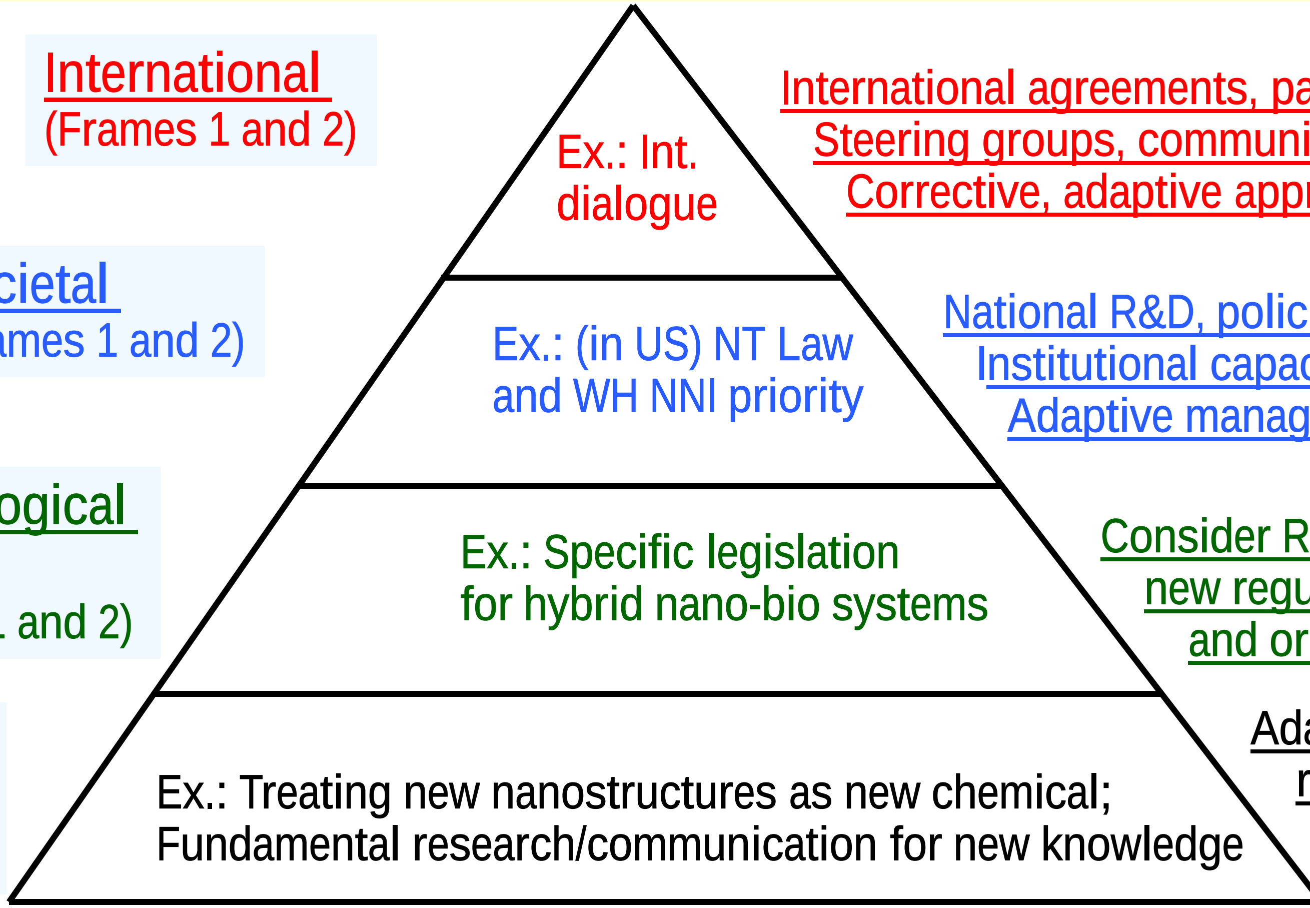
Implication Domain / Examples of RG activities / Implementation approach

International
(Frames 1 and 2)

Societal
(Frames 1 and 2)

Technological system
(Frames 1 and 2)

System component
(Frames 1)



International agreements, partnerships,
Steering groups, communication links
Corrective, adaptive approach

National R&D, policies and laws
Institutional capacity building
Adaptive management approach

Consider R&D programs
new regulations
and organizations

Adapting existing
regulations and
organizations

Reference: International Risk Governance Council, http://www.irgc.org/irgc/projects/nanotechnology/
Journal of Nanoparticle Research, Springer, 2008, Vol. 10, 11-29

Possibilities for a Global Governance of CT

C. Inclusiveness and partnership function

- Supporting partnerships between various stakeholders active in converging new technologies applications

- Global communication and information cross-sector, including for coordinated risk research strategies;

- Involving international organizations to advance multi stakeholder global challenges;

- Encourage international and cross-sector interactions

Possibilities for a Global Governance of CT

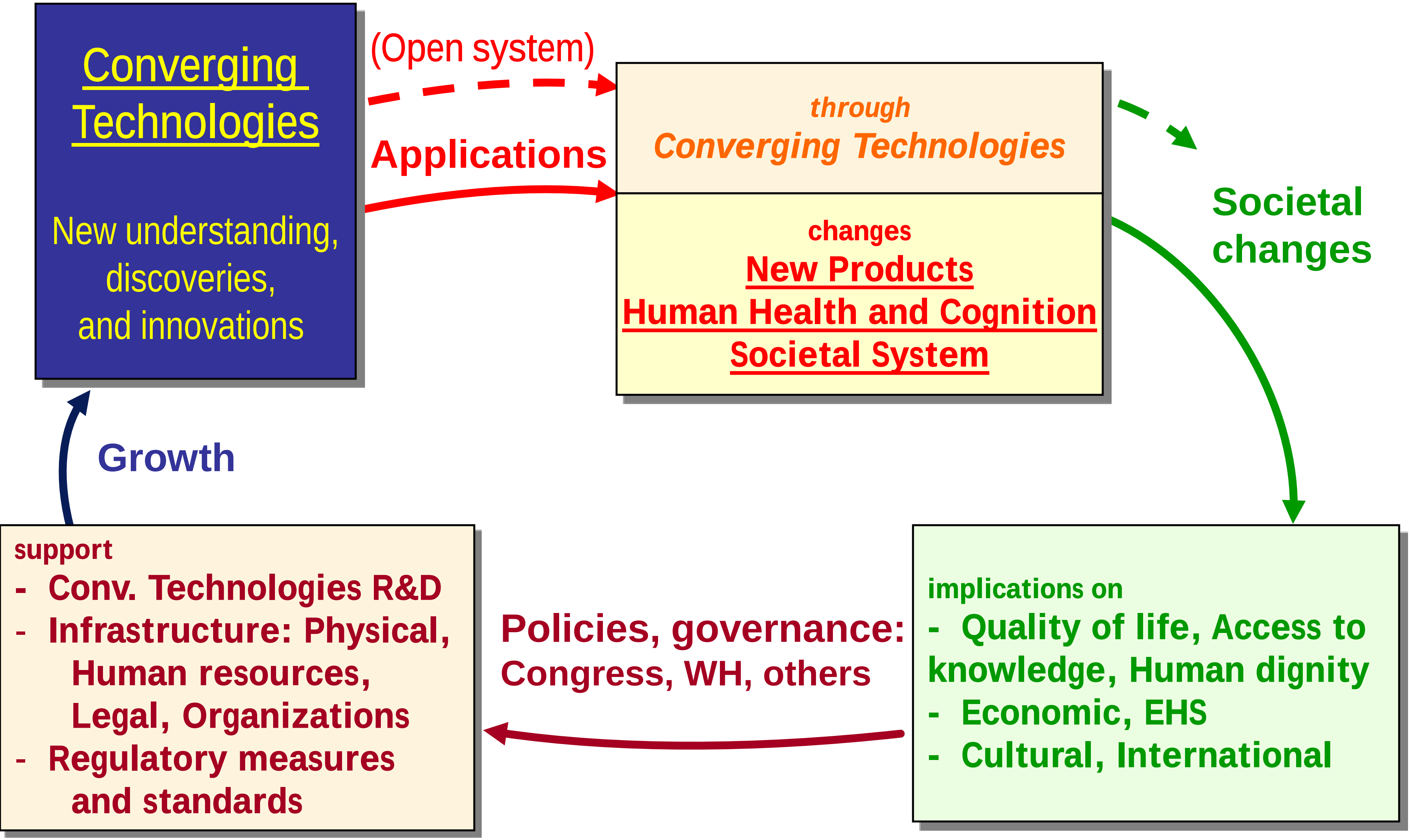
D. Commitment to long-term view

- Detecting earlier signs of change using international expert groups; adopt real time technology assessment

- Commitment to long-term planning using global scenarios and anticipatory measures on nanotechnology development

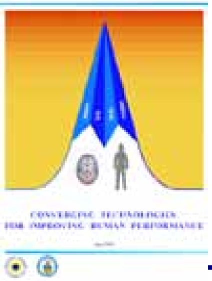
- Integrate development of emerging and converging technologies including of future generations of technology products

- Evaluate the trends for exponential growth of NBIC knowledge and technology capabilities



Converging Technologies in Society

J. Nanoparticle Research, 7(2), 2005; International Risk Governance Council, Report 2006



Several NBIC challenges for governance

- Create science and technology platforms for NBIC; and prepare earlier NBIC education
- Develop transforming capabilities, such as hybrid manufacturing, neuromorphic engineering, networking
- Understanding the nervous system, and the connection to mind, behavior, education and work productivity
- Develop capacity to anticipate and manage future opportunities and risks for deliberate and responsible developments; Include NBIC contribution in large programs

Topics

- ü Defining converging new technologies and core transforming tools (NBIC)
- ü Illustrations of research and education programs
- ü Global governance (policies, innovation, management) for societal benefit
- ü International study on transforming tools (NBIC2)

Areas of focus for international study NBIC2

1. Explore how discovery, education, innovation and application of different S&T domains could be made more compatible to increase societal benefits and human potential;   and identify emerging methodologies, systems of knowledge, technologies

2. Compare national R&D investments in the world for core NBIC transforming tools, their timeline and contribution in total S&E

3. Illustrate integration of S&E, technology and application areas

4. NBIC implications on individual and societal capabilities and benefits, including long-term human development and societal risks

5. Specific approaches in governance of CT-NBIC for societal benefit

Brainstorming Workshops

- **Latin America** (Sao Paolo, Brazil, Nov. 24-25, 2011)

  Workshop passworded website for draft contributions

- **United States**: co-sponsors Federal Agencies, AAAS, WWCS, NRC

- **European Union and Russia**

- **Asia (proposed Australia, China, India, Japan, Korea)**

NBIC2 study website: www.wtec/NBIC2/

Survey of the workshop contributors

- **What areas of CT-NBIC are most important?**
- **Provide successful examples of converging technology organizations and programs (types: holistic approach or collaboration driven)**
- **Suggest new directions for the next 10-20 years?**
- **General bibliography for NBIC 2**

Five possibilities for global CT governance

1. *Establish models and mechanisms for the global self-regulating ecosystem* to enhance discovery, education, innovation, nanoinformatics and commercialization

2. *Create and leverage S&T NBIC platforms* for new products in areas of highest societal interest

3. Develop CT for *common resources, evaluation methods, and risk requirements* (and organization?)

4. *Global communication and international partnerships*

5. Commitment to *long-term, priority-driven, global view* using scenarios and anticipatory measures

Several earlier references

(by M. Roco and co-authors)

“Coherence and Divergence of Megatrends in S&E” , Proc. Swiss Academies, 2000; also J. Nanoparticle Research, 2002, Vol. 4, 9-19

“Converging Technologies for Improving Human Performance” Springer/Kluwer in 2003

“Nanotechnology: Convergence with modern biology and medicine” Current Opinion in Biotechnology, 2003, Vol. 14, 337-346

“Co-evolution of Human Potential and Converging Technologies” Annals of the NY Academy of Sciences, 2004

“Converging science and technology at the nanoscale: Reversing the pyramid of learning“, Nature Biotechnology, 2003, 21: 1247-1250

“ Nanotechnology–Unifying and transforming tools”, AIChE J., 2004, 50(5)

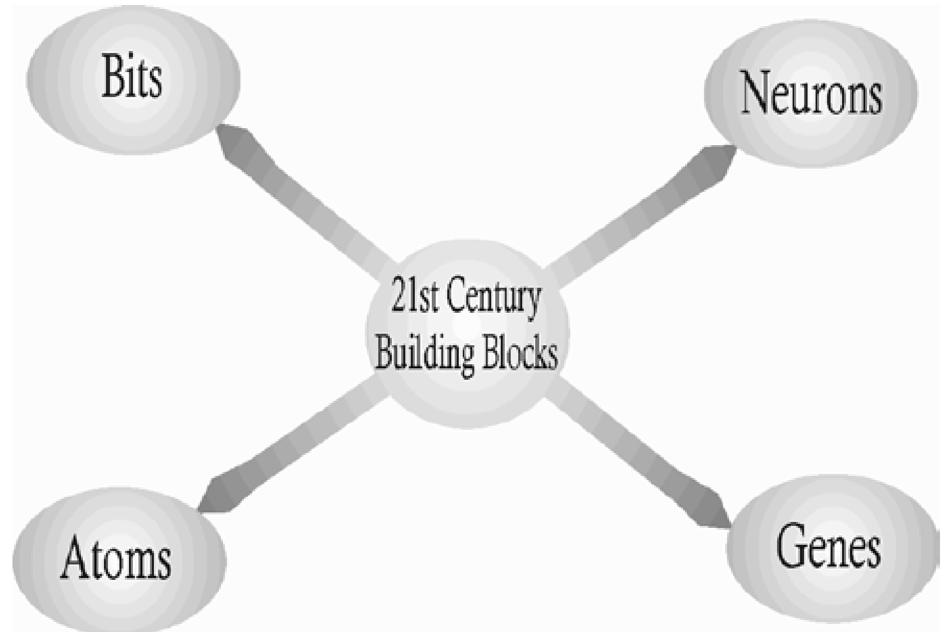
“ Managing Nano-Bio-Info-Cogno Innovations”, Springer, Nov. 2006

“ Global Governance of Converging Technologies”, J. Nanopart R., 2008, 10

“ Technology Convergence”, Leadership in S&T, Sage Publ., 2012

Tools of Convergence

Information technology Cognitive sciences



Nanotechnology Biotechnology

If the *Cognitive Scientists* can think it
the *Nano* people can build it
the *Bio* people can implement it, and
the *IT* people can monitor and control it

From a 2001 NBIC workshop participant (W.A.W.)